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## Comparison of Moisture Retention Curves for Representative Basaltic and Sedimentary Soils in Arizona Prepared by Two Methods

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### Abstract

Moisture retention curves were prepared for representative basaltic (silty clay loam) and sedimentary (sandy loam) soils in Arizona by two methods. With the vapor pressure method, small soil samples come into equilibrium moisture content with saturated salt solutions of known water potential. The other method measured the water potential of soil samples directly using thermocouple psychrometers. Both methods produced similar curves for the fine-textured basalt soil. However, the curves for the coarse-textured sedimentary soil were unequal. The vapor pressure method, the simplest, least expensive method for developing moisture retention curves, was reliable only for the fine-textured soil.

**Keywords:** Moisture retention curves, thermocouple psychrometer, vapor pressure, basalt soil, sedimentary soil

The evaluation of soil moisture in forestry research and general management practices frequently takes the form of quantitative measurements such as percent by weight or volume, or depth estimations. Another characteristic of soil moisture is water potential ( $\psi$ ), which is the energy or tension that must be overcome to remove the water, whether by plants or through evaporation. Therefore, soil water potential ( $\psi$ s) appears to be a better classification where plant response is of concern because, unlike quantitative categorization, the values are directly comparable regardless of soil characteristics.

Capabilities exist for evaluating  $\psi$  in situ by thermocouple psychrometry (Rawlins and Campbell 1986), by tensiometry (Cassel and Klute 1986), and by electrical resistance (Campbell and Gee 1986). An alternative

is to develop soil moisture retention curves (also known as drying curves, desorption curves, or moisture release curves) for individual soil types. These curves plot soil moisture content (SMC) against  $\psi$ s so a conversion of the easily measured SMC can be made.

In the laboratory, soil moisture retention curves can be developed by measuring SMC gravimetrically and plotting these values against  $\psi$ s determined by thermocouple psychrometers, pressure membranes, tensiometers, or by allowing soil samples to equilibrate with the vapor pressure of salt solutions of known  $\psi$  (Klute 1986). Advantages and disadvantages exist for each method. Thermocouple psychrometers are quite precise within the  $-0.1$  to  $-8.0$  MPa range and results are obtained rapidly. However, the equipment is expensive and sensitive. Pressure membranes and tensiometers are less expensive, but the most commonly available units measure  $\psi$ s only down to  $-1.5$  MPa and  $-0.1$  MPa, respectively. With the vapor pressure method, a wide range of  $\psi$ s can be determined by using a series of inexpensive salt solutions; however, several weeks are required for soil samples to reach equilibrium.

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As part of a comprehensive study of the water relations of southwestern ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) seedlings under drought conditions, moisture retention curves were developed for the two major forest soil types in Arizona. Curves were generated with data from thermocouple psychrometers and from the vapor pressure method, and both were supplemented at the higher  $\psi$  with data from the pressure membrane. The pressure membrane measures soil matrix potential while the psychrometer and vapor pressure methods determine total  $\psi$ s. Richards and Ogata (cited by Richards 1965) have shown that vapor pressure and pressure membrane measurements are in close agreement. Klute (1986) also indicates that if the osmotic component of water potential is negligible then the pressure membrane and thermocouple psychrometer give similar results. This paper discusses the methods used and compares the results in an attempt to recommend a simple, reliable method for developing moisture retention curves.

## METHODS

### Physical Soil Characteristic

Forest soils in the southwestern United States are primarily volcanic (derived from cinders or basalt rocks) or sedimentary (from sandstone or limestone) in origin. Textural characteristics for each broad soil type are similar over a wide geographical area (Heidmann 1975). Sedimentary soil (sandy loam classified as a Typic Eutroboralf) was collected from the top 15 to 20 cm on the Long Valley Experimental Forest, 96 km south of Flagstaff, AZ, at an elevation of 2195 m. Basalt soil (silty clay loam, a Typic Argiboroll) was collected from the same depth on the Fort Valley Experimental Forest 16 km northwest of Flagstaff, at an elevation of 2134 m. Soils were air-dried for several days then were passed through a 2-mm soil sieve. Soil bulk densities were determined by the sand cone method (Blake and Hartge 1986) and soil textures by the hydrometer method after organic matter had been removed by burning (Gee and Bauder 1986).

### Moisture Retention Curves

#### Equilibrium Vapor Pressure

Moisture retention curves were prepared by determining SMC at  $\psi$  -0.6 to -7.66 MPa by allowing soil samples to come into equilibrium with solutions of known  $\psi$ . Salt solutions with a range of  $\psi$  were prepared according to Spencer (1926), Hodgman (1962), and Greenspan (1977). These calculated  $\psi$  were checked with a thermocouple psychrometer.

After the solutions were prepared with distilled water, 400-ml samples were placed into separate glass desiccator jars. Four small, shallow, metal soil cans containing 5 g of moist soil were then placed on perforated ceramic plates suspended over the solutions in each jar.

A partial vacuum was applied to the jars, which were placed in a growth chamber and kept at 20°C in constant darkness. After 2 weeks, the soil samples were removed from the jars and were weighed to the nearest 0.1 mg on an analytical balance. Samples were replaced in the jars and placed back in the growth chamber under vacuum. Thereafter, samples were weighed weekly until the change in weight was 5 mg or less.

### Thermocouple Psychrometer Method

Thermocouple psychrometers estimate  $\psi$ s by directly measuring the relative vapor pressure of the sample being tested. Screen-caged thermocouple psychrometers were used within stainless steel calibration chambers similar to those described by Brown and Bartos (1982). The psychrometers were previously calibrated using six KCl solutions with  $\psi$  ranging from -0.2 to -6.5 MPa. Linear regressions were developed for each psychrometer using  $\psi$  as the dependent variable and psychrometer output in microvolts as the independent variable. All regressions had  $r^2 > 0.99$ .

Development of moisture retention curves followed techniques described by Campbell et al. (1966). Tests were run for each of the two soil types. A series of 50-g, air-dry samples were moistened with distilled water in soil cans. Each sample was then allowed to dry for different periods of time. After specific drying had been achieved, each soil can was sealed and shaken intermittently until the sample became homogeneous. A portion of the sample was then placed into the calibration chamber surrounding the psychrometer, and the rest was used to gravimetrically determine SMC. The psychrometer chamber was sealed and placed into a water bath at 25°C. Water potential of the samples was measured after equilibrium was reached in the chamber, usually after 3 hours. After three measurements were taken at hourly intervals, a mean  $\psi$ s was determined which corresponded to a specific SMC. A series of trials were run until a range in  $\psi$ s was achieved from -0.1 to about -7.0 MPa. Pressure membrane data were used to supplement both methods in the wet region with SMC corresponding to  $\psi$ s of 0.00, -0.03, and 0.25 MPa (Heth and Kramer 1985).

### Analysis

The SMC/ $\psi$ s relationships are generally power functions (Roundy 1983, Saxton et al. 1986). Specific functions for each soil were determined by regression analysis. Differences between models by methods were determined using the extra sums of square method (Draper and Smith 1981).

## RESULTS AND DISCUSSION

A comparison of the physical characteristics of the two soils is shown in table 1. The coarse texture of the sedimentary soil is evidenced by its having nine times



Table 1.—Physical characteristics of basalt and sedimentary soils in Arizona (means of four samples and standard deviation(s)).

Characteristic	Soil			
	Sedimentary		Basalt	
	$\bar{x}$	SD	$\bar{x}$	SD
Bulk density, g/cm <sup>3</sup>	1.74	0.40	1.18	0.03
Composition, %				
Sand	72.50	0.00	8.90	1.60
Silt	17.10	0.04	55.10	1.40
Clay	10.40	0.40	36.00	2.80
Organic matter	0.38	0.18	2.23	0.93

the sand and one-third as much silt and clay as the basalt soil. Soil moisture contents at saturation for the sedimentary and basalt soils are 25.4% and 47.7% by weight, respectively, and at field capacity (−0.03 MPa) are 9.9% and 35.4% by weight, respectively.

The nonlinear regressions developed for both soils by both methods are typical of moisture retention curves (Campbell et al. 1966) and are shown in figure 1. Our curves resemble those prepared by Pharis (1966), who determined lethal points for several conifers grown in “builders sand” and Glade pumice soil. The inflection point of our sedimentary soil is about 1.5% lower than that of Pharis’ curve for “builders sand,” but otherwise the curves are similar.

The shapes of the soil moisture retention curves are quite similar for most soils, i.e.,  $\psi_s$  stays at a high level (low negative value) until SMC reaches a critical point (inflection point) then with a slight drop in SMC,  $\psi_s$  drops dramatically. There is some variation in steepness of curves as well as in inflection points, depending on soil type. For our two soils, curves prepared using the vapor pressure method are visually similar to those prepared using thermocouple psychrometers (fig. 1). The regression equations are statistically different between methods, however (table 2). The primary reason for

Table 2.—Comparison of soil moisture retention curves for two Arizona soils developed by two methods.

#### Basalt soil

Vapor pressure method:

$$\text{Water potential (−MPa)} = 281996.64/\text{SMC}^{4.989}$$

$$R^2 = 0.95, \text{ Standard error of estimate} = 0.55$$

Thermocouple psychrometer method:

$$\text{Water potential (−MPa)} = 61466.84/(\text{SMC})^{4.359}$$

$$R^2 = 0.99, \text{ Standard error of estimate} = 0.16$$

Method comparison:

$$F_{2, 50} = 11.97 \text{ (} p < 0.001 \text{)}$$

#### Sedimentary soil

Vapor pressure method:

$$\text{Water potential (−MPa)} = 9.13/(\text{SMC})^{3.046}$$

$$R^2 = 0.80, \text{ Standard error of estimate} = 1.12$$

Thermocouple psychrometer method:

$$\text{Water potential (−MPa)} = 9.45/(\text{SMC})^{4.659}$$

$$R^2 = 0.96, \text{ Standard error of estimate} = 0.35$$

Method comparison:

$$F_{2, 63} = 11.16 \text{ (} p < 0.001 \text{)}$$

statistical differences is that, in specific regions of the curves, there are substantial vertical differences at particular soil moisture values.

Even though statistical differences are indicated, it may be of interest to see where the differences specifically exist. For the basalt soil, the regressions are very similar at the wetter soil moisture and, in fact, converge at about 11% moisture content (−1.8% MPa). Divergence slowly increases as the soil dries further, but is probably not biologically significant until moisture drops below 10% where corresponding water potential differences increase beyond 0.2 MPa. At this level of soil dryness (< 3.0 MPa), moisture is certainly limiting plant processes and is nearing an unavailable status. Therefore, if the curves developed by the two methods are biologically

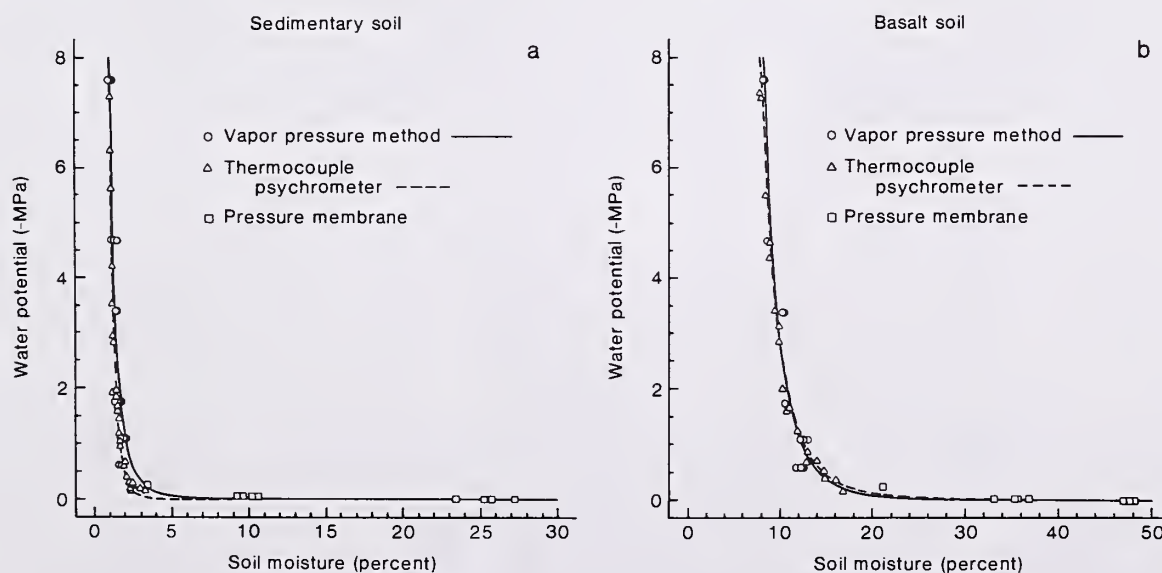


Figure 1.—Soil moisture retention curves prepared by using the vapor pressure and thermocouple psychrometer methods and supplemented by pressure membrane data: (a) sedimentary soil; (b) basalt soil.



different only in the very dry region, for practical purposes, they can be assumed to be equal. Stafford (1985) reminds us that a statistically significant test indicates that observed differences are probably not caused by chance alone, but it does not tell us if differences are biologically important.

A different situation exists for the moisture retention curves of the sedimentary soil; convergence occurs in the dry region where soil moisture is basically unavailable. Proceeding from the dry region to the wet region, percent differences between the two curves increase until both sides are moist enough to be biologically similar (above 4% moisture content). For example, at the classic wilting point ( $-1.5$  MPa), soil moisture from the vapor pressure curve is 1.8%. Using 1.8% moisture in the thermocouple psychrometer curve yields a water potential of  $-0.6$  MPa. This estimated water potential discrepancy could result in plant response differences. Because divergence continues into the moister region, the regressions and the methods that determined them cannot be considered similar for this sedimentary soil.

### SUMMARY

Soil moisture retention curves may be generated easily without using instruments that are expensive or difficult to operate such as thermocouple psychrometers, pressure membranes, or tensiometers. A few chemicals, desiccator jars, a delicate balance, oven, a dark room, and a room with a stable temperature can be used to implement the vapor pressure method. If the chemicals we used are unavailable, sodium chloride at various molar concentrations may be substituted (Lang 1976).

The equilibrium vapor pressure method, which indirectly determines soil water potential from that of known salt solutions, appeared to produce water retention curves of variable accuracy depending on soil texture when compared to curves developed by direct measurement. Regressions for the coarse-textured soil in which water potential changes very rapidly with minimal moisture changes were not reliable. In contrast, regressions for the fine-textured soil were similar in regions of biological significance using either the thermocouple psychrometer or the vapor pressure method.

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